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Short Communication

Thermal ecology of three potentially at-risk species of Mexican kinosternid turtles

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Abstract

Surprisingly little is known about the thermal ecology of Mexican kinosternid turtles. We studied the body temperatures of *Kinosternon cora*, *K. durangoense*, and *K. herrerai* from Mexico. Mean body temperatures of the three species were 25.0 °C for *K. cora*, 21.9 °C for *K. durangoense*, and 23.3 °C for *K. herrerai*. Body temperature (T_b) in *K. cora* were negatively related to water temperatures (T_w). Body temperatures in *K. cora* were lower than T_w and the differences between T_b and T_w increased with T_w. In both *K. durangoense* and *K. herrerai*, T_b increased with both T_a and T_w. In *K. durangoense*, T_b was higher than T_w below ≈ 22 °C and lower than T_w above ≈ 22 °C. In *K. herrerai*, T_b was higher than T_w below ≈ 23.5 °C and lower than T_w above ≈ 23.5 °C. Males and females did not differ in T_b in all three species. Our results suggest a role for environmental temperatures—especially water temperature—in determining body temperature in these three species of Mexican *Kinosternon*. However, our results also suggest that these turtles can maintain T_b different from their aquatic habitat, suggesting at least a limited ability to thermoregulate.

Key words: *Kinosternon cora*, *Kinosternon durangoense*, *Kinosternon herrerai*, Mexico, thermal ecology, thermoregulation

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Introduction

For ectotherms that depend on the environment for their body temperature, climate change is likely to be challenging (Hayden Bofill and Blom 2024). Indeed, various groups of reptiles appear to be increasingly at risk of extinction at the species or population level due to climate change (e.g., lizards: Sinervo et al. 2010, 2024; Holzmann et al. 2023; Wild et al. 2025; turtles: Ihlow et al. 2012; Biber et al. 2023). The ability to control body temperature via thermoregulation may permit some reptiles to buffer climate change's effects on environmental temperature (Kearney et al. 2009; Chessman 2019). It is therefore

important to study the thermal ecology of a species, and in particular whether it is a thermoregulator or thermoconformer, to understand the possible effects of climate change on it (see Butler 2019).

Climate change is expected to influence the future distributions of kinosternid turtles (Butler et al. 2016; Weaver et al. 2022; Liao et al. 2024), including leading to the possible extinction of some species (Berriozabal-Islas et al. 2020). However, relatively little is known about the thermal ecology of kinosternid turtles. Mean body temperatures for kinosternid turtles have been found to range from 19.8 °C to 33.29 °C (Table 1). Previous work has also suggested that kinosternids are thermoconformers, with strong correlations between environmental and body temperatures (Mahmoud 1969; Berriozabal-Islas 2018).

Here, we report the results of field studies of the body temperatures of three species of *Kinosternon*: *K. cora*, *K. durangoense*, and *K. herrerai* from Mexico (Fig. 1), which houses more species of kinosternid turtles than any other country (Ennen et al. 2016). Such information is particularly needed since *K. durangoense* and *K. herrerai* (*K. cora* was not assessed) are among the species of *Kinosternon* identified as being at risk of going extinct due to climate change (Berriozabal-Islas et al. 2020). Thus, a better understanding of their thermal ecology is important to more fully determine their susceptibility to future climate change. This is especially true given the relatively small distributions of these three species and their potentially tenuous conservation status. Indeed, species with limited distributions and habitats appear to be particularly prone to extinction due to climate change (e.g., Berriozabal-Islas et al. 2018; Muñoz-Nolasco et al. 2023).

The limited distribution of *K. cora* is found within the states of Sinaloa and Nayarit (Loc-Barragán et al. 2020; González et al. 2025); however, climatic niche models suggest appropriate climatic conditions for it are more widely distributed in Nayarit, Sinaloa, and Durango and warrant further investigation (Loc-Barragán and Castro-Bastidas 2025). *Kinosternon cora* has not been assessed by the IUCN Red List; however, Loc-Barragán et al. (2020) suggested it be given some form of protection under Mexican law. Indeed, its abundance appears to be low inside its known range (Loc-Barragán and Iverson 2024). Within its limited distribution, numerous threats likely exist, including water

Table 1. Mean body temperatures (T_b) of kinosternid turtles.

Species	Mean T_b (°C)	Source
Kinosternon chimalhuaca	24	Raya-García et al. (2024)
Kinosternon chimalhuaca	21.3	Berriozabal-Islas (2018)
Kinosternon flavescens	25.06	Mahmoud (1969)
Kinosternon herrerai	20.56	Berriozabal-Islas (2018)
Kinosternon hirtipes	19.2	Berriozabal-Islas (2018)
Kinosternon integrum	19.34	Pérez Pérez (2022)
Kinosternon oaxacae	21.34	Berriozabal-Islas (2018)
Kinosternon subrubrum	23.65	Mahmoud (1969)
Staurotypus salvinii	29.92	Dean (1980)
Sternotherus carinatus	33.29	Mahmoud (1969)
Sternotherus odoratus	21.2	Edgren and Edgren (1955); Brattstrom (1965)
Sternotherus odoratus	24.14	Mahmoud (1969)

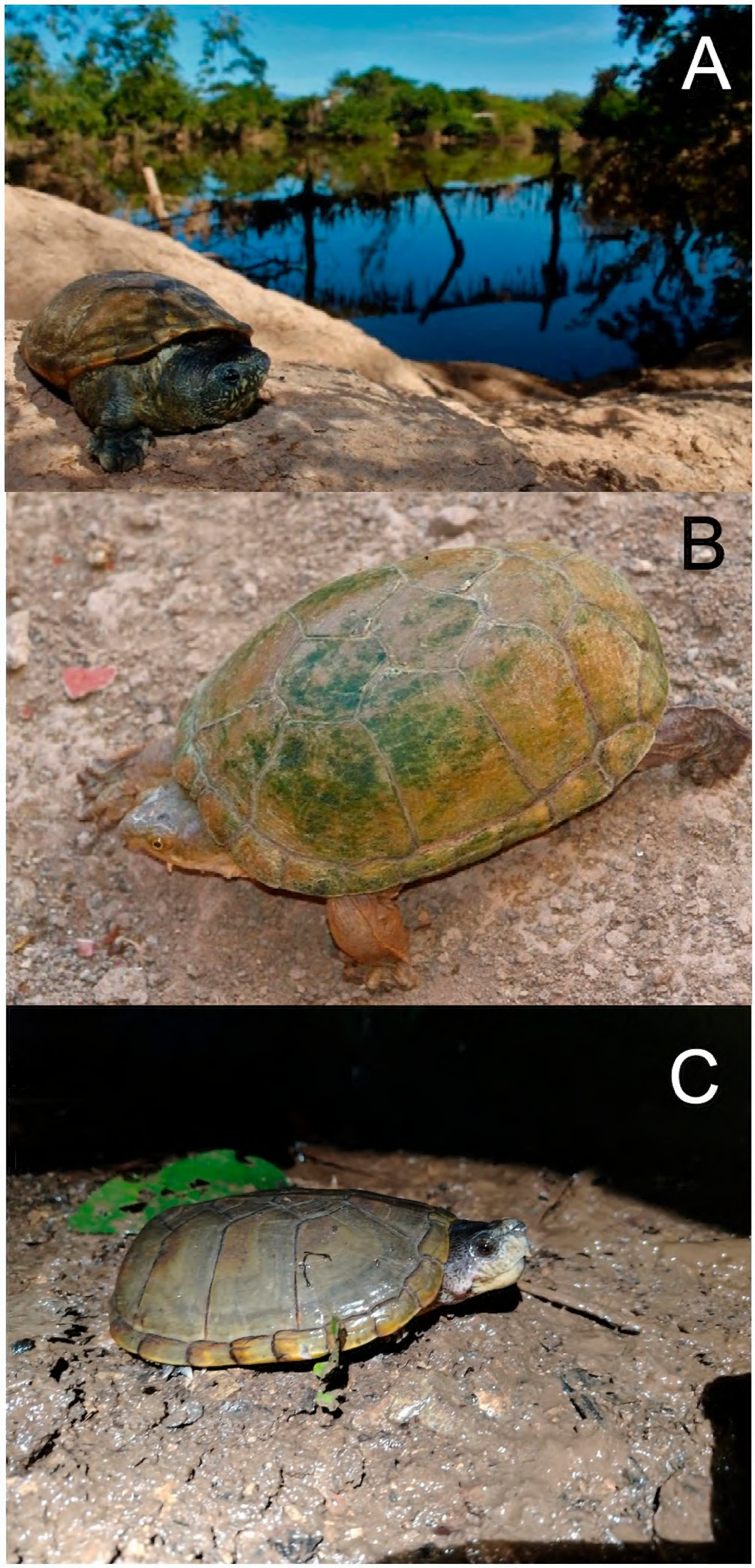

Figure 1. Photographs of the three species studied. **A.** *Kinosternon cora*; **B.** *K. durangoense*; **C.** *K. herrerai*.

and chemical use by agriculture (Loc-Barragán et al. 2020). Very little is known about its ecology, and what is known primarily comes from its description by Loc-Barragán et al. (2020) and anecdotal observations in Loc-Barragán and Iverson (2024). *Kinosternon durangoense* has a very limited distribution in the Mexican states of Chihuahua, Coahuila, and Durango (Iverson 1979; Legler and Vogt 2013; Iverson et al. 2018b), and its ecology is relatively unstudied (Iverson et al. 2018a), leading to its listing as Data Deficient in the IUCN Red List (van Dijk 2007). *Kinosternon herrerai* is considered Near Threatened by the IUCN Red List, with the major threats being over-exploitation for food and medicinal uses and the use of water for agriculture (van Dijk et al. 2007). *Kinosternon herrerai* is distributed in the states of eastern Mexico, including Hidalgo, Mexico, Puebla, San Luis Potosí, Tamaulipas, and Veracruz (Berry and Iverson 1980; Mata-Silva et al. 2002; Legler and Vogt 2013), and has long been considered rare (e.g., Shannon and Smith 1949), with relatively little known about its biology (Carr and Mast 1988; Aguirre-Léon and Aquino-Cruz 2004; Legler and Vogt 2013; Mimila-Manzur et al. 2023).

Methods

Study sites

Kinosternon cora was studied in multiple areas (Table 2; Fig. 2). We collected *K. cora* from three permanent pools with depths between 0.80 and 1.20 m in the municipality of Rosario (12 June 2021, *N* = 1) and from the municipality of Escuinanpa (12 June 2021, *N* = 3) at elevations between 10 and 15 m in Sinaloa. The vegetation at both sites was tropical dry forest. We also sampled *K. cora* from natural pools with depths > 1 m and areas between 18 and 79 m^2 in the municipalities of Tecuala (12 July 2021, *N* = 1); Acaponeta (12 July 2021, *N* = 6); Tuxpan (12 June 2021, *N* = 1); Rosamorada (12 July 2021, *N* = 2); and Ruiz (12 June 2021, *N* = 3), Nayarit, at altitudes ranging from 0 to 30 m. The dominant vegetation in this region is tropical deciduous forest.

Table 2. Geographic details of study sites used for studying the thermal ecology of three species of Mexican *Kinosternon*.

	State	Latitude, Longitude
K. cora		
Rosario	Sinaloa	22.962669, -105.927070
Escuinanpa	Sinaloa	22.531758, -105.450767
Escuinanpa	Sinaloa	22.540235, -105.469190
Tecuala	Nayarit	22.195562, -105.421991
Acaponeta	Nayarit	22.409732, -105.303575
Tuxpan	Nayarit	22.007847, -105.344581
Rosamorada	Nayarit	22.063732, -105.240094
Ruíz	Nayarit	21.919952, -105.091297
K. durangoense		
Bolsón de Mapimi	Junction of Chihuahua, Durango, and Coahuila	26.899444, -103.787833
K. herrerai		
Cuetzalán	Puebla	20.021189, -97.472310

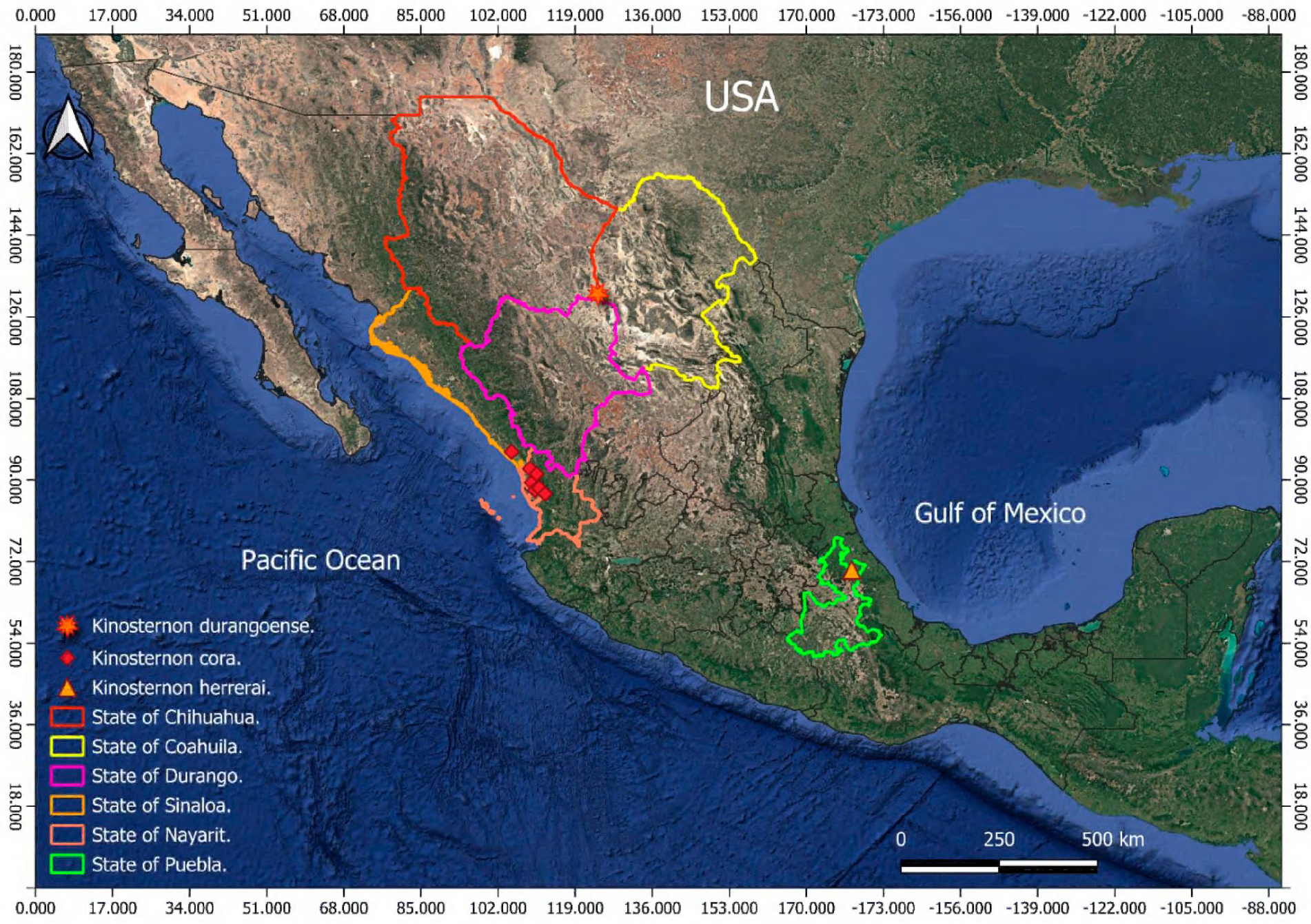

Figure 2. Distributions of the study sites for the three species of *Kinosternon*.

Kinosternon durangoense was studied in a temporary cattle watering hole with an estimated depth of 0.60 m and area of 380 m^2 at an elevation of 1120 m in the Bolsón de Mapimí at the junction of Chihuahua, Durango, and Coahuila (Table 2; Fig. 2; 16 June 2022, $N = 43$). The vegetation in the study area is desert shrubland.

We studied *K. herrerai* from the municipality of Cuetzalán, Puebla, at 630 m elevation (Table 2; Fig. 2). Sampling was carried out in two pools with depth < 1 m and areas between 37 and 83 m^2 (25 September 2022, $N = 9$; 8 October 2022, $N = 7$; 5 November 2022, $N = 3$; 24–25 November 2022, $N = 3$). Typical vegetation of the study area is tropical sub-deciduous forest.

Temperature measurements

For all sampled localities, we used five randomly placed collapsible box-shaped traps (60 cm long x 60 cm wide x 20 cm high with a 1.5 cm mesh) baited with canned tuna or sardines and with two empty 2-L bottle floats. We checked traps every 30 minutes, typically for several hours, including both day and night. We caught *K. cora* only at night, *K. durangoense* only during the day, and *K. herrerai* during both day ($N = 19$) and night ($N = 3$). Preliminary analyses showed that there were no differences in any temperatures between day and night for *K. herrerai* (Wilcoxon test: $p > 0.11$ in all cases), so we pooled the data for analyses.

For each turtle, we measured body temperature (T_b; cloacal), air temperature (T_a; 2 cm above the water surface at the trap or capture site), and water temperature (T_w; 3 cm below the water surface at the trap or capture site) to

the nearest 0.1 °C using a Fluke model 52-11 digital thermometer. Ernst et al. (2014) found that the mean T_b of *Chelydra serpentina* that had been trapped (traps checked twice daily) was identical to the mean T_b of actively moving *C. serpentina*, suggesting the T_b of trapped turtles may be a reasonable estimate of active T_b. We also determined the sex for each captured turtle. We released turtles at their capture site once all variables were collected.

Statistical analysis

Prior to analyses, we examined the assumptions of parametric tests, and when there were any violations of those assumptions, we used non-parametric tests. We used linear regressions to examine the relationship between T_w, T_a, and T_b for each species. We calculated the difference between T_b and T_w for each individual. For each species, we used a Wilcoxon signed-rank test to compare the mean T_b – T_w difference to 0. We used an analysis of variance (ANOVA) to compare T_w and T_a between males and females and an analysis of covariance (ANCOVA) with T_w as the covariate to compare T_b between males and females of each species to determine if T_b differed independently of environmental temperatures. We used an ANOVA to compare the T_b – T_w differences between months for *K. herrerai*. We also used an ANCOVA with T_w as the covariate to compare T_b among months for *K. herrerai*. We used T_w as the covariate since it had a stronger relationship with T_b (i.e., r^2 was higher) than did T_a. In all cases, the interaction between T_w and sex or month were not significant, indicating that the slope of the T_b on T_w regression did not differ between males and females or among months for *K. herrerai*. We therefore removed the interaction term from the final ANCOVA model. The α-value used to determine statistical significance was 0.05. Means are given ± 1 S.E.

Results

Kinosternon cora

Overall, mean T_b was 25.0 ± 0.1 °C (N = 17). Mean T_a was 20.6 ± 0.1 °C (N = 17), and mean T_w was 25.4 °C ± 0.1 °C (N = 17). Body temperature was not related to T_a but was negatively related to T_w (Table 3).

Males and females did not differ in mean T_a ($F_{1,15}$ = 0.48, p = 0.50) or T_w ($F_{1,15}$ = 0.21, p = 0.64) (Table 4). Male and female *K. cora* did not differ in mean T_b (Table 4; ANCOVA: $F_{1,14}$ = 0.02, p = 0.88). Body temperature was negatively related to T_w (ANCOVA covariate: $F_{1,14}$ = 4.58, p = 0.05).

The mean difference between T_b and T_w (−0.39 ± 0.14 °C; N = 17) for *K. cora* was significantly less than zero (Wilcoxon signed-rank test = −49.0, p = 0.018). The difference increased with T_w (Fig. 3A; N = 17, r^2 = 0.76, p < 0.0001; [T_b – T_w] = 37.4–1.49T_w).

Kinosternon durangoense

Mean T_b was 25.0 ± 0.1 °C (N = 43), mean T_a was 20.4 ± 0.1 °C (N = 43), and mean T_w was 21.7 ± 0.2 (N = 43). Body temperature increased with T_a and T_w (Table 3).

There was no difference between males and females in mean T_a ($F_{1,41}$ = 0.51, p = 0.48) or T_w ($F_{1,41}$ = 0.81, p = 0.37) (Table 4). Mean T_b did not differ between

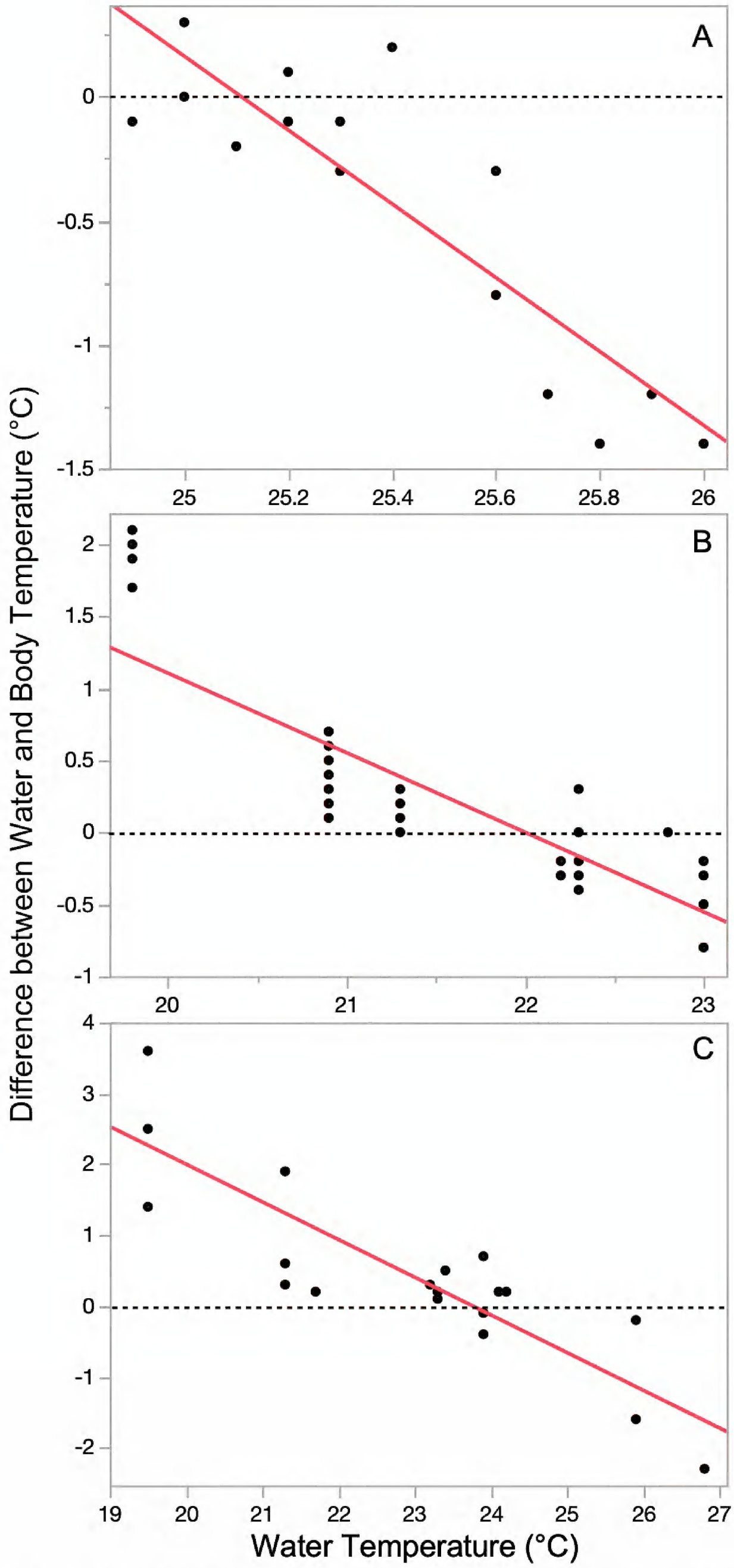

Figure 3. Relationship between water temperature (T_w) and the difference between body temperature and water temperature (T_b–T_w) for *Kinosternon cora* (**A**), *K. durangoense* (**B**), and *K. herrerai* (**C**).

Table 3. Relationships between body temperature (T_b) and environmental temperatures (air temperature, T_a; water temperature, T_w) for three species of Mexican *Kinosternon*.

	N	r^2	*p*	Equation
K. cora				
T_b vs. T_a	17	0.058	0.35	
T_b vs. T_w	17	0.25	0.040	$T_b = 37.4 - 0.49T_w$
K. durangoense				
T_b vs. T_a	43	0.39	< 0.0001	$T_b = 12.4 + 0.46T_a$
T_b vs. T_w	43	0.62	< 0.0001	$T_b = 12.2 + 0.45T_w$
K. herrerai				
T_b vs. T_a	22	0.73	< 0.0001	$T_b = 7.72 + 0.70T_a$
T_b vs. T_w	22	0.72	< 0.0001	$T_b = 12.6 + 0.47T_w$

Table 4. Mean (± 1 S.E.) body temperature (T_b), air temperature (T_a), and water temperature (T_w) of males and females of three species of *Kinosternon* from Mexico (*N* given in parentheses).

	T_b (°C)	T_a (°C)	T_w (°C)
K. cora			
Males (9)	25.0 ± 0.1	20.6 ± 0.1	25.3 ± 0.1
Females (8)	25.0 ± 0.1	20.7 ± 0.1	25.4 ± 0.1
K. durangoense			
Males (18)	22.0 ± 0.1	20.5 ± 0.2	21.8 ± 0.2
Females (25)	21.7 ± 0.1	20.4 ± 0.2	21.6 ± 0.2
K. herrerai			
Males (6)	23.6 ± 0.5	22.8 ± 0.6	23.7 ± 0.9
Females (16)	23.2 ± 0.3	22.2 ± 0.4	22.5 ± 0.5

male and female *K. durangoense* (Table 4; ANCOVA: $F_{1,40} = 2.65$, $p = 0.11$). Body temperature increased with T_w (ANCOVA covariate: $F_{1,40} = 64.04$, $p < 0.0001$).

The mean difference between T_b and T_w (0.17 ± 0.10 °C; $N = 43$) was not significantly different from zero (Wilcoxon signed-rank test = 76.0, $p = 0.36$). The difference between T_b and T_w decreased with T_w (Fig. 3B; $N = 43$, $r^2 = 0.71$, $p < 0.0001$; $[T_b - T_w] = 12.16 - 0.55T_w$), with the difference positive at $T_w <\approx$ 22 °C and negative at $T_w >\approx$ 22 °C).

Kinosternon herrerai

Kinosternon herrerai had a mean T_b of 23.3 ± 0.2 °C ($N = 22$), a mean T_a of 22.4 ± 0.3 °C ($N = 22$), and a mean T_w of 22.8 ± 0.4 °C ($N = 22$). There was a positive relationship between T_b and T_a and between T_b and T_w (Table 3).

Male and female *K. herrerai* did not differ in mean T_a ($F_{1,20} = 0.61$, $p = 0.44$) or T_w ($F_{1,20} = 1.56$, $p = 0.23$) (Table 4). Body temperature did not differ between males and females (Table 4; ANCOVA: $F_{1,19} = 0.27$, $p = 0.61$). Body temperature increased with T_w (ANCOVA covariate: $F_{1,19} = 48.4$, $p < 0.0001$). The mean difference between T_b and T_w (0.5 ± 0.28 °C; $N = 22$) was significantly greater than zero (Wilcoxon signed-rank test = 71.0, $p = 0.017$). The difference between T_b and T_w decreased with T_w (Fig. 3C; $N = 22$, $r^2 = 0.77$, $p < 0.0001$; $[T_b - T_w] = 12.65 - 0.53T_w$), such that below ≈ 23.5 °C the difference was positive (i.e., $T_b > T_w$) but above ≈ 23.5 °C the difference was negative (i.e., $T_b < T_w$).

Mean T_a of *K. herrerai* was higher in September and November compared to October (Table 5; $F_{2,19}$ = 15.32, p = 0.0001) as was mean T_w (Table 5; $F_{2,19}$ = 126.78, p < 0.0001). Mean T_b did not differ among months once T_w was taken into account (i.e., least squares means, Table 5; ANCOVA, $F_{2,18}$ = 0.083, p = 0.92). Body temperature increased with T_w (ANCOVA covariate: $F_{1,18}$ = 11.9, p = 0.0029). The difference between T_b and T_w was greater in October relative to September and November (Table 5; $F_{2,19}$ = 12.32, p = 0.0004).

Table 5. Mean (± 1 S.E.) air temperature (T_a), water temperature (T_w), body temperature (T_b), least squares mean of T_b (T_b LSM), and difference between body and water temperature (T_b–T_w) for three months in *Kinosternon herrerai* from Mexico (*N* given in parentheses). Means sharing letters are not significantly different (Tukey HSD post-hoc).

	T_a (°C)	T_w (°C)	T_b (°C)	T_b LSM (°C)	T_b–T_w (°C)
September (9)	22.5 ± 0.25	23.6 ± 0.13	23.7 ± 0.15	23.4 ± 0.2	0.16 ± 0.30[b]
October (7)	20.9 ± 0.04	20.3 ± 0.36	22.1 ± 0.31	23.3 ± 0.4	1.83 ± 0.34[a]
November (6)	23.8 ± 0.63	24.6 ± 0.78	24.1 ± 0.50	23.3 ± 0.4	−0.53 ± 0.37[b]

Discussion

The mean T_b of the three species of *Kinosternon* we studied ranged from 21.9 °C in *K. durangoense* to 25.0 °C in *K. cora*. These mean T_{bs} are at the lower end of the range of T_{bs} observed in other kinosternid species (see Table 1). Body temperatures in these three species appear to be predominantly determined by T_w, which generally had the same or stronger relationship with T_b than did T_a. This pattern makes sense given the highly aquatic nature of these turtles and the general rarity of aerial basking in *Kinosternon* (Mahmoud 1969; Iverson 1986; Mitchell and Johnston 2012; Platt and Medlock 2015; Pittfield and Burger 2017; Raya-García et al. 2024; but see Iverson 1989). It is also consistent with the strong correlation (r > 0.95) between T_b and T_w in *K. subrubrum*, *K. flavescens*, *S. odoratus*, and *S. carinatus* (Mahmoud 1969). There are many possible explanations for why different species and populations of *Kinosternon* show different mean T_b. For example, the differences among species and populations could be driven by habitat type, latitude, or diel activity periods (e.g., nocturnal vs. diurnal). However, our results that T_b is strongly related to T_w indicate that whatever is the cause, it is likely driven by environmental temperature fluctuations. Our study contributes additional data on the thermal ecology of different species of *Kinosternon*, but more data are needed to evaluate these potential explanations. Thus, further investigation of the thermal ecology of more species and populations of *Kinosternon* is needed.

Berriozabal-Islas (2018) determined that kinosternid turtles are generally thermoconformers with estimates of thermoregulatory efficiency for four species ranging from 0.3 to 0.69. However, the situation appears to be more nuanced in these three species of *Kinosternon*. A potential role for thermoregulation is suggested by our results for the difference between T_b and T_w. In particular, both *K. durangoense* and *K. herrerai* appear to show a threshold T_w below which they have T_bs greater than T_w and above which they have T_bs below T_w. Interestingly, these threshold temperatures, 22 °C for *K. durangoense* and 23.5 °C for *K. herrerai*, are similar to the laboratory-selected temperatures of four species of Mexican *Kinosternon* (19.2 °C to 21.34 °C), with *K. herrerai* having a selected

temperature of 20.5 °C (Berriozabal-Islas 2018) and 23–25 °C in *K. chimalhuaca* (Raya-García et al. 2024). These observations suggest that these aquatic turtles may be capable of maintaining their T_b near the preferred temperature, assuming the preferred temperatures in our populations are similar to those determined by Berriozabal-Islas et al. (2018) and Raya-García et al. (2024). Edgren and Edgren (1955) also found that *Sternotherus odoratus* had T_b higher than T_w when T_w was low and T_b lower than T_w when T_w was high.

Interestingly, the significant relationship between T_b and T_w for *K. cora* was negative (i.e, T_b decreased with T_w). In part this may reflect the relatively narrow range of T_w available during our monitoring of *K. cora*, and thus there may have been little scope for an increase in T_b with T_w. However, the T_ws for *K. cora* were substantially warmer than those for the other two species. *Kinosternon cora* may have been actively reducing their T_b relative to T_w as T_b increased. Indeed, the mean difference between T_b and T_w was below zero (i.e., T_bs were, on average, cooler than T_w in *K. cora*). Further evidence for this comes from the increase in the difference between T_b and T_w with T_w.

We found no differences in mean T_b, T_a, and T_w between males and females for any of the three species of *Kinosternon*. Given the strong effect of environmental temperatures on T_b in these species, it is not surprising that there was no difference in T_b of males and females since they used the same areas of water and thus experienced the same T_w. We are aware of only one other study that quantitatively compares the T_b of male and female *Kinosternon*. Pérez Pérez (2022) found female *K. integrum* from Estado de México had higher mean T_b than males, likely due to longer basking durations. Mahmoud (1969) did find little difference in the thermal ecology of male and female *K. subrubrum*, *K. flavescens*, *S. odoratus*, and *S. carinatus*, but the differences were not quantitatively assessed. Picard et al. (2011) found that female *S. odoratus* in the St. Lawrence River in Canada maintained higher T_b than males, especially when the females were gravid.

Conclusion

Our results suggest a substantial role for environmental temperatures, especially T_w, on the T_b of these three species of *Kinosternon*, with both the relationships between environmental temperatures and T_b and the differences in T_b among months being driven by T_w. However, it also appears that these turtles are also able to maintain their T_b different from T_w. These results suggest that they may have some limited ability to buffer increases in environmental temperature due to climate change. Future studies that explore how these turtles may be able to maintain their T_bs at a different temperature from their environment and whether this will be enough to avoid the most severe consequences of climate change are needed (see also Butler 2019).

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

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Use of AI

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Author contributions

GAW: Conceptualization, Investigation, Data Curation, Funding Acquisition, Writing-Editing and Review; GRS: Data Analysis, Writing-Original Draft; JAL-B: Conceptualization, Investigation, Data Curation; RLR: Investigation; EJT-R: Investigation; JAL-E: Conceptualization, Investigation.

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Data availability

All of the data that support the findings of this study are available in the main text.

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